Fossil *Eucalyptus* Remains from the Middle Miocene Chalk Mountain Formation, Warrumbungle Mountains, New South Wales

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HOLMES, W. B. K., HOLMES, F. M., & MARTIN, H. A. Fossil *Eucalyptus* remains from the Middle Miocene Chalk Mountain Formation, Warrumbungle Mountains, New South Wales. *Proc. Linn. Soc. N.S.W.* 106 (4), (1982) 1983: 299-310.

Eucalyptus fruits and leaves are preserved in the diatomite of the Middle Miocene Chalk Mountain Formation (new name), Warrumbungle Mountains, New South Wales. The fossil eucalypts show some features of advanced states in fruit and venation and are compared with some extant species. Based on present knowledge of *Eucalyptus* **sensu lato**, the fossils provide evidence of two separate phylogenetic lines being present in Middle Miocene time. The microflora recovered from the diatomite and associated lignite includes pollen grains of Myrtaceae (*Myrtaceidites* spp) of which a few are referable to *Eucalyptus*.

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INTRODUCTION

Despite the present day prominence of *Eucalyptus* and the great diversity of its species, little is known of its evolutionary history from the fossil record (Martin, 1978; Briggs and Johnson, 1979). For phytogeographical reasons alone, there can be little doubt that the genus is of ancient Australian origin (Barlow, 1981); however, the 'eucalypt-type' pollen, *Myrtaceidites eucalyptoides* Cookson and Pike, which is probably bloodwood-*Angophora* first appears in the Oligocene (Martin, 1981). Fossil leaves which resemble eucalypts in gross form but which were inadequately described and figured, have been recorded from many poorly-documented Tertiary localities in New South Wales, Victoria, Tasmania, South Australia and Central Australia. References to these occurrences are given in Duigan (1951). Lange (1978) reported a diverse assemblage of Lepidospermae fruit, including a number of forms closely similar to *Eucalyptus*, preserved as impressions on silicified slabs of unknown age from the arid zone of South Australia. Ambrose *et al.* (1979) have also collected *Eucalyptus* fruit similarly preserved to those of Lange. The age of these fossils from Stuart Creek, northwest of Lake Torrens in South Australia is thought to be either Eocene-Oligocene or Miocene.

Deane (1902) described several forms of eucalypt-like leaves from the Berwick Quarry in Victoria. A re-investigation of this flora by Nelson and Webb (in prep.) has shown that the cuticle of one of the leaves is similar to the cuticle of some extant *Eucalyptus*. Impressions of a eucalypt-like fruit and of rainforest leaves are also present but no *Eucalyptus* type pollen has been observed in the microflora which is dominated by *Nothofagus* pollen (Nelson and Webb, pers. comm.).

Eucalyptus fruit and leaves and the microflora from the Middle Miocene diatomite deposit at Bugaldie near Coonabarabran in northwestern New South Wales are described below. Associated with the eucalypts are remains of leaves and flowers of plants (Holmes, in prep.) which have affinities with extant plants growing in situations with a much higher rainfall than the present Bugaldie average annual rainfall of 650 mm. Also in the diatomite are fossils of fish (Hills, 1946), a bird described as an owlet-nightjar (Rich and McEvey, 1977), diatoms (Thomas and Gould, 1981 a and b), insects and freshwater bivalves.

Geology and Age of the Diatomite

Chalk Mountain, which lies 6 km south of Bugaldie village, is a remnant of an extensive dissected plateau of late Permian, Triassic and Jurassic freshwater sediments capped by basalt associated with the Warrumbungle Volcano Complex to the south. Lacustrine sediments which are interbedded between basalt flows on the Jurassic sediments and a 25 metre thick overlying basalt flow, outcrop around the escarpment of Chalk Mountain. Diatomite in these sediments was commercially exploited from 1919 until 1980. Griffin (1961) gave a detailed description of the geological and commercial aspects of the deposit but he did not name the formation. Reports by Herbert (1968a and b) deal with the diatomite.

Chalk Mountain Formation (Holmes and Holmes, new name). The Chalk Mountain Formation is a lake deposit over 15 metres in thickness and is composed of almost horizontal layers of mudstone, clay, diatomite, three interbedded horizons of tuffaceous clay and a thin band of lignite. The type locality is Quarry A on the western face of Chalk Mountain immediately below the basalt flow capping the mountain (grid reference 199148, Gilgandra 1: 250 000 Geological Series Sheet SH 55-16). The base of the formation is obscured at this locality by the basaltic talus slope and by quarry waste. On the roadway up the northern slope of the mountain the basal beds of mudstone and clay rest on basalt. The section exposed in Quarry A is shown in Table 1.

The area of lake sediments that have disappeared due to erosion around Chalk Mountain is unknown, but it is likely that the original lake was very much larger than the 38 hectares of the existing deposit. Plant macro-fossils have been collected only from the diatomite. Plant micro-fossils occur in both the diatomite and the thin band of lignite near the top of the formation. For a horizontal distance of about thirty metres in from the outcropping face, the diatomite has weathered to a pure white lightweight material much of which has been removed by open-cut mining and some tunnelling. Beyond the weathered zone the diatomite is of a grey to black colour due to the presence of organic matter and is known as 'black earth'. The 'black earth' was only sparingly exploited due to the necessity to process it to remove the organic matter. In the weathered zone of the diatomite the plant macro-fossils are preserved as colourless or limonite-stained impressions and in the unweathered zone as colourless impressions

Table 1

Type Section of Chalk Mountain Formation exposed in Quarry A on Chalk Mountain, Bugaldie (after Griffin, 1961)

Top	Basalt
4.26 m	Clay with lignite band
0.91 m	Tuff, clay and grit
4.05 m	Clay and diatomite
0.13 m	Tuff, clay, diatomite and gritty sandstone
3.04 m	Diatomite high grade
0.08 m	Clay and tuff
0.81 m	Diatomite high grade
3.0 m	Mudstone, tuff and clay
Bottom	Basalt, trachyte and andesite overlying Jurassic Pilliga Sandstone

or carbonaceous compressions. The diatomite exhibits seasonal varves each 0.33 mm to 0.5 mm thick (Thomas and Gould, 1981b). A deposition time of between 14 000 and 21 000 years would have been needed to accumulate the total thickness of 7 metres of diatomite, assuming the varves to be annual.

The bands of tuff within the deposit indicate contemporaneous eruptive volcanic activity during the period of lacustrine sedimentation. K/Ar dating of igneous rocks from localities around the Warrumbungle complex (Dulhunty and McDougall, 1966; McDougall and Wilkinson, 1967; Wellman and McDougall, 1974) show that the volcanic activity took place during the period 17 million years to 14 million years before the present. The nearest sites to Chalk Mountain with K/Ar dates are Looking Glass Mountain (16.6 ± 0.6 m.y.), 15 km to the west-northwest, and Woorut Mountain (15.5 ± 0.4 m.y.), 20 km to the south (Wellman and McDougall, 1974). As no study has been made of the geology of the northern portion of the Warrumbungle Volcano, the stratigraphic relationships of these localities to Chalk Mountain are not known. Therefore, with present information, we can only date the diatomite as being within the age limits of the active Warrumbungle Volcano — 17 million years to 14 million years, Middle Miocene.

The Fossil Eucalypts

Family MYRTACEAE

Genus *Eucalyptus* L'Hérit.

Eucalyptus bugaldiensis Holmes and Holmes sp. nov.

Fig. 1 **A**, Fig. 2 **A-D**

Diagnosis: Fossil infructescence of a group of three umbellasters of seven or fewer small,

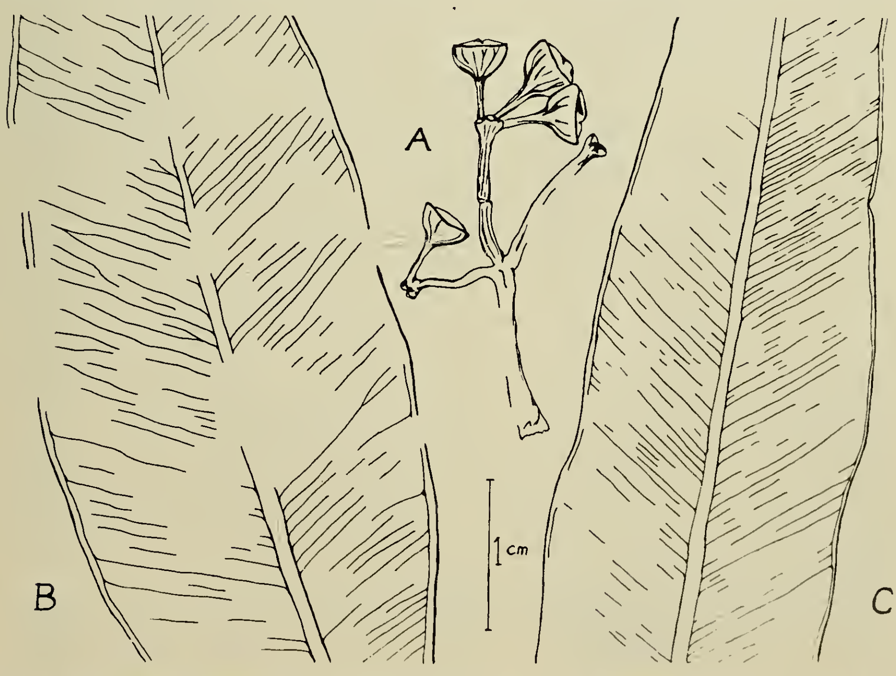

Fig. 1. **A** *Eucalyptus bugaldiensis* sp. nov. AMF61713 holotype × 2. **B** *Eucalyptus* sp. Leaf form B AMF61721 × 2. **C** *Eucalyptus* sp. Leaf form A AMF61724 × 2.

hemispherical, ribbed, woody fruit attached by tapering pedicels to peduncles. Rim of fruit broad; exerted valves broad and low.

Description: Infructescence of three umbellasters on peduncles 5 mm – 10 mm in length, and 0.8 mm in width attached at a common point to a stem. Umbellasters composed of seven or fewer fruit attached to the peduncle apex by pedicels (anthopodia) 5 mm – 10 mm in length widening upwards to merge into the base of the fruit. Fruit hemispherical, 4 mm – 5 mm in diameter. External surface ornamented by 7 – 10 longitudinal ribs which occasionally fork near the rim. Rim flat ca 1 mm in width. Exerted valves forming a broad low triangular projection 0.5 mm above the rim.

Type material: Holotype AMF61713 and counterpart AMF61714. Paratypes AMF61715–20. The Australian Museum, Sydney, N.S.W., Australia.

Type locality: Diatomite beds in Quarry A on Chalk Mountain, 6 km south of Bugaldie village near Coonabarabran, New South Wales. Grid reference 199148, Gilgandra 1: 250 000 Geological Series Sheet SH 55–16. Chalk Mountain Formation, Middle Miocene.

Discussion: The fossil fruits of *Eucalyptus bugaldiensis* are preserved as impressions in the soft diatomite. The hollow moulds contain no organic material. The surface of the diatomite was hardened with Bedacryl 122X and latex casts were then taken of the holotype and its counterpart. When whitened with ammonium chloride, the latex casts revealed some of the finer details not readily seen in the original specimens. The distal ends of the peduncles show scars where additional buds or fruits have been aborted or lost during development or preservation. The umbellaster on AMF61715 has five fruit attached by pedicels to the peduncle. In addition to the still-attached fruit, the distal end of the peduncle shows the abscission scars of another two pedicels. This suggests that the total flower number per umbellaster was seven, a number which may be expected in dichasial inflorescences in a family with primarily opposite and decussate phyllotaxy. Extant species in subgenus *Symphyomyrtus* very often have seven flowered umbellasters. The arrangement on the holotype of three umbellasters about a common point, is found in the eucalypt conflorescence sub-types of T_1 and S_3 of Johnson (1972, fig. 3). The T_1 sub-type characterizes the small tropical subgenus *Telocalyptus* (section *Equatoria*) and the S_3 sub-type occurs mainly in the subgenus *Eudesmia*, but the fossil fruits are quite different from any in *Eudesmia*. However, three umbellasters can be so attached in some variants of sub-type S_6 also (L. A. S. Johnson, pers. comm.) when the phyllotaxy in the inflorescence region is opposite rather than disjunct-opposite (Briggs and Johnson, 1979), as for instance in some inflorescences of *Eucalyptus microtheca* of subgenus *Symphyomyrtus* section *Adnataris*. The infructescence and the individual fruits of *E. bugaldiensis* are very close in form to some extant species of *Eucalyptus*. However, due to the type of preservation and to the lack of supporting organs, this new species cannot at present be placed with certainty in any particular subgenus.

The fruits of *E. microtheca* F. Muell. (Blake, 1953, pl. 30, figs 20-36) are closely similar in size and form to those of *E. bugaldiensis*. *E. microtheca* is very widely distributed throughout the continent (Blake, 1953, map 24) on ground that is subject to seasonal flooding. *E. raveretiana* F. Muell. from areas near the coast in central and northern Queensland has similar but rather smaller fruit.

None of the diverse forms of fossil *Eucalyptus* fruits from South Australia (Lange, 1978; Ambrose *et al.*, 1979) appear to be similar to *E. bugaldiensis* but their different aspect of preservation makes comparisons difficult. The cluster of fruits from Berwick, Victoria (Nelson and Webb, in prep.) is superficially similar to *E. bugaldiensis* but lacks evidence of valves.

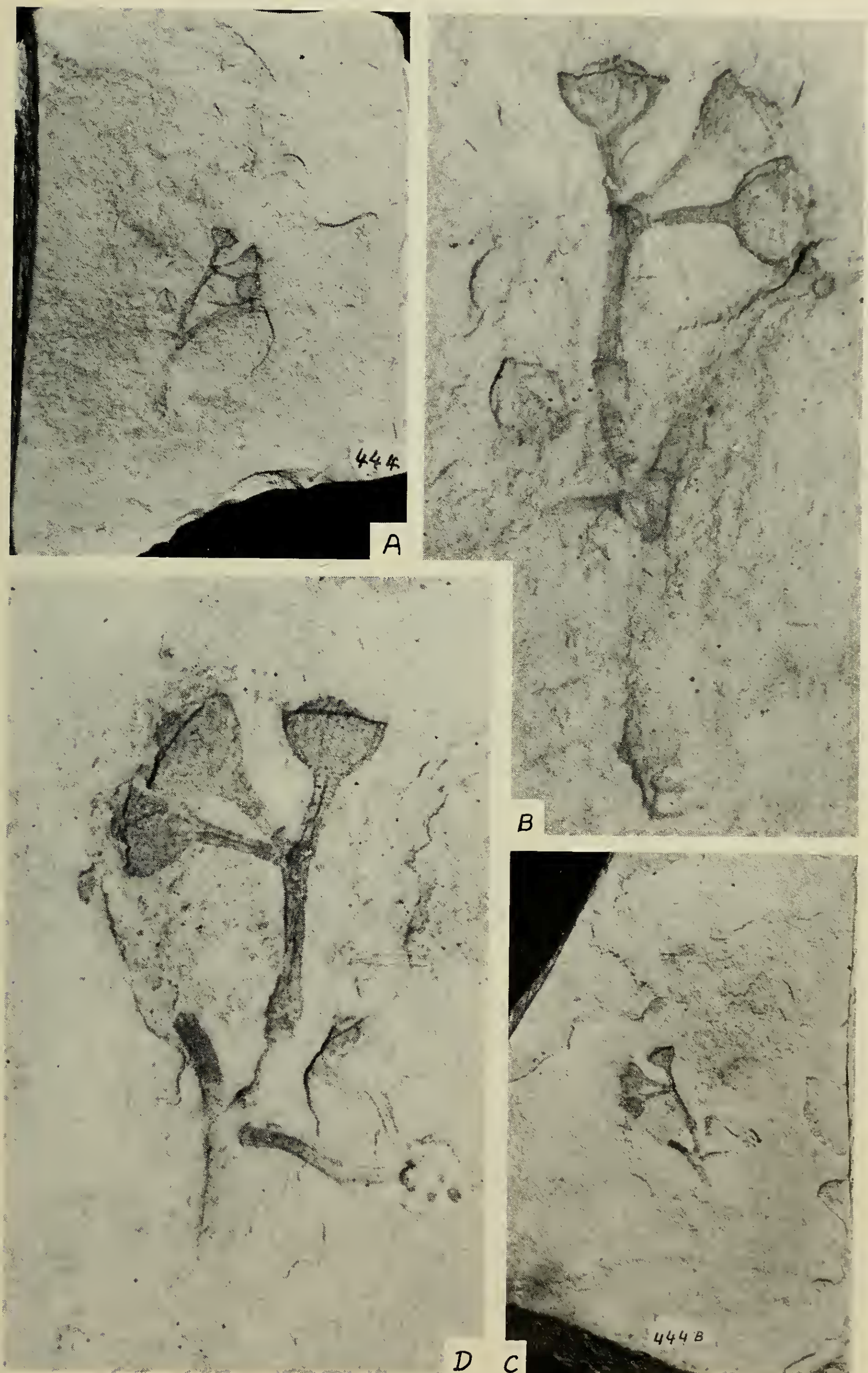

Fig. 2. **A-D** *Eucalyptus bugaldiensis* Holmes & Holmes sp. nov. Holotype. **A, B** AMF61713, **A** × 1; **B** × 4. **C, D** AMF61714 counterpart of AMF61713, **C** × 1; **D** × 4.

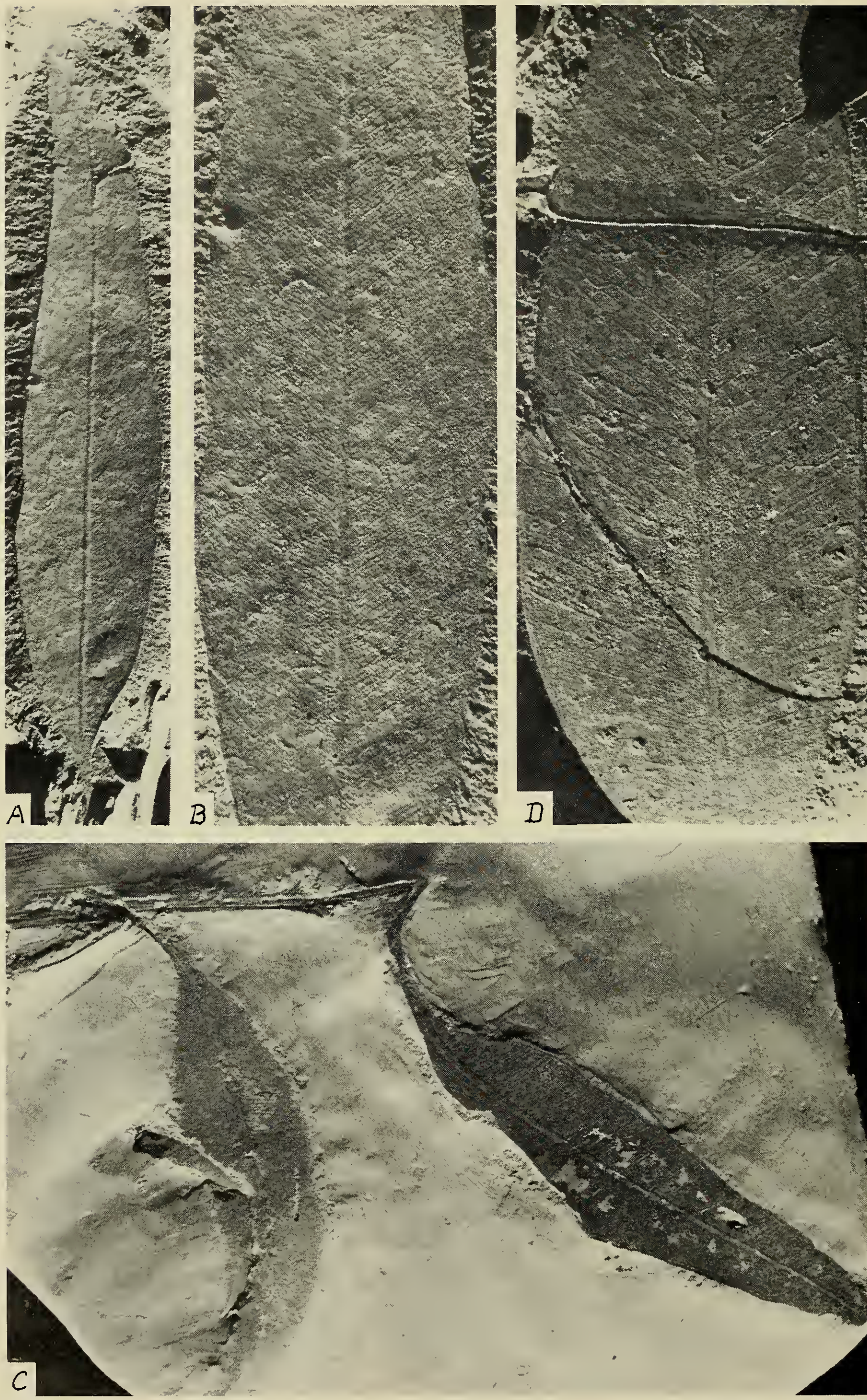

Fig. 3. **A, B** *Eucalyptus* sp. Leaf form A AMF61724 **A** × 1, **B** × 2. **C, D** *Eucalyptus* sp. Leaf form B MMF15284 × 1, **D** AMF61721 × 2.

Eucalyptus sp. Leaf-form A
Fig. 1 **C**, Fig. 3 **A-B**

Description: Leaf lanceolate to narrow lanceolate, falcate, asymmetrical about lamina base; margin scarious, entire, sometimes insect-damaged. Length 8 cm–14 cm; width 1.5 cm–2 cm, widest at one quarter of length from the base and tapering gradually to an obtuse apex. Petiole curved, to 2 cm in length. Midvein prominent, tapering from the petiole to the apex. Secondary veins parallel, ca 1 mm apart, sometimes with a minor vein in between; attached to the midvein at 50°–60° and running straight to the intramarginal vein which runs close and parallel to the leaf margin. Tertiary veins form an irregular reticulum of about four rows of areoles between the secondary veins.

Material: AMF61721–3.

Discussion: The venation pattern of leaf-form A is of the Transversae class (Cambage, 1913; Maiden, 1922) (not to be equated with the section Transversaria of Pryor and Johnson, 1971) and is present in the subgenera *Corymbia* and *Blakella* of *Eucalyptus* and in *Angophora* which Pryor and Johnson (1971) have suggested is also of subgeneric rank in *Eucalyptus* s.l. Extant species with venation similar to leaf-form A are the widespread *Angophora floribunda* (Sm.) Sweet and *Eucalyptus trachyphloia* F. Muell., a bloodwood tree, which grows on the drier sandy soils of the Upper Hunter River and Pilliga areas of New South Wales and into Queensland.

Eucalyptus sp. Leaf-form B
Fig. 1 **B**, Fig. 3 **C-D**

Description: Leaf lanceolate, slightly falcate; margin entire; apex obtuse; lamina base asymmetrical. Width 16 mm–23 mm; length 8 cm–12 cm. Secondary veins sub-parallel, spaced irregularly, 5–6 per cm, running a slightly undulate course to the intramarginal vein at an angle of 55°–60° to the midvein. Secondary veins occasionally fork and anastomose to form a very elongate reticulum. Petiole curved, to 2 cm in length.

Material: AMF61724–5. MMF15284.

Discussion: MMF15284 (Fig. 3 **C**) shows portions of five leaves, one of which is attached to a slender stem which has sub-opposite projections from where the other leaves may have become detached. Leaf-form B differs from leaf-form A by the wider spaced and irregular course of the secondary veins. The venation pattern is intermediate between the Transversae and Obliquae classes (Cambage 1913; Maiden 1922). This general pattern of leaf venation is present in extant species within the subgenus *Symphyomyrtus* section *Adnataria* series *Oliganthinae* or series *Pruinosae* and in the subgenus *Telocalyptus* series *Degluptae*. Leaves of *Eucalyptus raveretiana* F. Muell. (a member of *Telocalyptus*) bear a close resemblance to this fossil form.

Palynology of the Chalk Mountain Formation (H.A.M.)

Table 2 lists the taxa found in the 'black earth' diatomite and in the lignite from near the top of the formation. Preservation is rather poor which limits identifications, and this may be the result of initial poor conditions at the time of deposition or of subsequent weathering on exposure. Nevertheless, the assemblages are workable and invaluable because they can be dated by independent evidence.

The two assemblages are essentially the same, although there is a quantitative difference between the diatomite and the lignite. This difference could result from the different conditions of deposition. Diatomite is formed in lakes and so would accumulate more wind-blown pollen. Because lignite forms in swamps most of the pollen

TABLE 2

The Pollen Frequencies

Fossil Name	Botanical Affinity	Diatomite %	Lignite %
ALGAE			
Botryococcus braunii Kützing	*Botryococcus braunii*	+	
FERN SPORES			
Cyathea paleospora Martin	*Cyathea* spp.	1.5	2.9
Deltoidospora inconspicua Martin	—	1.5	2.4
Laevigatosporites ovatus Wilson & Webster	—	1.5	5.6
Polypodiidites sp.	—		0.5
Reticuloidosporites minisporis Martin	—		0.2
Unknown spore	—		5.4
	Total Fern Spores	4.6	17.2
GYMNOSPERMS			
Araucariacites australis Cookson	*Agathis* and *Araucaria*	10.7	18.1
Cupressaceae sp. indet	Cupressaceae	0.8	2.2
Dacrydium florinii (Cookson & Pike) Cookson	*Dacrydium* Sec. B	4.6	1.0
Phyllocladus palaeogenicus Cookson & Pike	*Phyllocladus* spp.		0.5
Podocarpus australiensis (Cookson & Pike) Martin	*Podocarpus* Sect. Dacrycarpus	5.3	5.4
Podocarpus elliptica (Cookson) Martin	*Podocarpus*, most other sections	7.6	10.5
	Total Gymnosperms	29.0	34.8
ANGIOSPERMS			
Cupanieidites orthoteichus Cookson & Pike	Tribe Cupaneae (Sapindaceae)	+	
Ericipites sp.	Epacridaceae		1.2
Graminidites media Cookson	Gramineae		0.2
Haloragacidites harrisii (Couper) Harris	*Casuarina*	13.0	24.0
Loranthaceae	Loranthaceae		0.2
Malvacipollis diversis Harris	*Austrobuxus—Dissiliaria* (Euphorbiaceae)	+	
Milfordia sp.	Restionaceae		+
Monosulcites cf Palmae	Like Palmae		0.7
Myrtaceidites eucalyptoides Cookson & Pike	Bloodwood—*Angophora*, possibly other genera		0.5
Myrtaceidites cf *M. eucalyptoides* Cookson & Pike	Possibly other eucalypts	0.8	
M. parvus Cookson & Pike	Possibly *Tristania—Backhousia—Baeckia* and other genera	6.8	0.2
Myrtaceae not identified further	Myrtaceae	17.5	5.2
	Total Myrtaceae	25.2	3.2
Nothofagus aspera Cookson	*Nothofagus*, the *menziesii* type (e.g. *N. moorei*, *N. cunninghamii*)	0.8	0.5
N. emarcida Cookson	*Nothofagus*, the *brassii* type	1.5	
	Total *Nothofagus*	2.3	0.5
Polyporina chenopodiaceoides Martin	Chenopodiaceae and some Amaranthaceae	0.8	
Proteacidites sp.	Proteaceae		+
Quintinia psilatispora Martin	*Quintinia*		2.0
Tricolporites scabratus Harris	—	3.0	
Tricolporites cf Cunoniaceae	like Cunoniaceae		0.7
Tricolporites cf Goodeniaceae	like Goodeniaceae		0.2
Tricolporopollenites ivanhoensis Martin	probably Rutaceae		0.2
Triorites minisculus McIntyre	—		0.2
T. orbiculatus McIntyre	—		1.0
Triorites cf Ulmaceae	like *Apananthe—Celtis*		0.2
Unknown tricolpate/tricolporates	—	22.1	13.2
		No.	No.
Number of kinds of unknowns		7	6

Notes:

(1) Subtotals may not add up exactly because individual percentages have been rounded off.

(2) + indicates a presence but not counted.

(3) The use of 'like' indicates a tentative identification.

would come from the plants growing in and around the edges of the swamps. Fern spores are more abundant and diverse in the lignite. The swamp environment would be more suitable for fern growth. Gymnosperms are well represented in both assemblages but are slightly more abundant in the lignites and of this group, Araucariaceae are the most common. *Casuarina* is almost twice as abundant in the lignites. Some species of *Casuarina* grow on the swamp edges today.

The Myrtaceae are more abundant in the diatomite than in the lignite. Unfortunately, the identification of pollen to genera within this family is not particularly reliable. The bloodwood-*Angophora* type is only found in the lignite in a very low concentration. Judging from surface samples, Rose (1981) found that this pollen type does not disperse aerially far from the source of production. However, water transport cannot be ruled out; but swamp vegetation would act as a filter and prevent the pollen from travelling far (Birks and Birks, 1980). The other 'possibly eucalypt' type is smaller than the bloodwood-*Angophora* type, and Rose found that it is more widely distributed. This second type has been found only in the diatomite. Myrtaceous pollen which is not like that of eucalypts is also present (see Table 2). The majority of the pollen cannot be identified beyond the family level because of poor preservation or crumpling which obscures diagnostic features.

Nothofagus is present but in very low concentration, indicating transport from a distant source. The small amount of the *brassii* type may have come from plants growing a long way from the catchment of this lake. Little can be said of the taxa present in low frequencies, for these are usually low pollen producers. The indeterminate tricolpate/tricolporate group is quite abundant. These pollen assemblages must represent forests, judging from the low content of herbaceous elements such as Gramineae and the absence of Compositae.

The high content of Myrtaceae in the diatomite together with the low content of *Nothofagus* in both samples fits the Myrtaceae phase of the Pliocene (Martin, 1973). *Malvacipollis diversus* and *Triporopollenites ivanhoensis* are usually found only in the lower part of the older phase (Martin, unpubl.). The Pliocene age was based only on the general geology of the Riverina region (Martin, 1973), so it may not be reliable. None of the diagnostic species of the mid-late Miocene *Triporopollenites bellus* Zone, described from the Gippsland Basin of south eastern Victoria (Stover and Partridge, 1973), has been found at Chalk Mountain and the general description of this Zone is a poor fit for the present assemblages. The base of this Zone contains abundant *Nothofagus* which decreases upwards through it. Its upper limit possibly extends into the Pliocene but the relationship to the overlying Myrtaceae phase (older) has not been documented. The problem is one of geographic variation during the Tertiary. In time-equivalent assemblages, *Nothofagus* is more abundant in southeastern Victoria than in New South Wales. Conversely, Myrtaceae are more abundant in New South Wales, particularly in the most westerly sites (Martin, 1983). Since the change from an assemblage with high *Nothofagus* to one with high Myrtaceae depends on the climate becoming drier, this change should have occurred earlier in the drier, inland regions than on the wetter coastal southeastern part of Australia. The Chalk Mountain microfloral assemblages show that the change had occurred in this region by the mid Miocene, some 14–17 million years ago.

The Middle Miocene Chalk Mountain Palaeoenvironment

The Tertiary pollen record is largely that of rainforest assemblages (Martin, 1978, p. 200) and most deposits of plant macro-fossils show a preponderance of mesophyllous leaves which constituted the *'Cinnamomum'* flora (Sussmilch, 1937). The preservation of pollen and other plant remains as fossils usually depends on the presence of lakes, swamps or bogs. Therefore, a strong bias exists against the fossilization of plants adapted to growing in drier and harsher environments. Beadle (1981) has suggested that scleromorphic plants began to differentiate at the margins of rainforests and developed along declining soil-fertility gradients. Johnson and Briggs (1981) discussed the possibility of differentiation of scleromorphic taxa during the Early Tertiary in nutrient-deficient forest sites. The large tracts of low-fertility soils derived from the underlying Jurassic Pilliga Sandstone surrounding the Warrumbungles would have provided such an environment.

At the present time eucalypts characteristically occur in open forest and woodland associations and only a few species have been successful in rainforest margins (Barlow, 1981). In addition to the eucalypt remains, the Chalk Mountain fossil flora includes fern fragments, podocarp leaves, *Ceratopetalum* sp. flowers and myrtaceous, lauraceous and other leaves that show similarities in gross form with present-day rainforest species in high rainfall areas of northeastern New South Wales and eastern Queensland. This mixed fossil flora should not be regarded as evidence that eucalypts in the Middle Miocene were adapted to rainforest conditions. Two present-day environmental situations provide a similar mixture of leaves. In moist sclerophyll forests on the North Coast of New South Wales, rainforest will develop, in the absence of fire, beneath tall *Eucalyptus* trees such as *E. grandis* W. Hill ex Maiden, *E. saligna* Sm. and occasionally *E. microcorys* F. Muell. Along the coastal strip of New South Wales and Queensland, rainforest species sometimes form a fringing forest along the banks of watercourses. Sclerophyll forest abuts and often overhangs this rainforest. Leaf-litter in the stream bed is a mixture of eucalypt and rainforest plant remains.

At Chalk Mountain in Middle Miocene time, the rich soils derived from the basalt, the moist conditions adjacent to the lake, and the probable higher rainfall (Kemp, 1978) would have favoured rainforest growth. Sandstone hills around the lake and areas away from the soil-improving influence of the basalt would have supported a sclerophyll forest or woodland to provide the eucalypt, herb and grass remains that would have been carried by wind or water to mingle with the rainforest remains in the lake sediments. The high percentage of gymnosperm and *Casuarina* pollen probably indicates the proximity of these plants to the site of deposition.

Conclusion

On the basis of leaf venation, the Chalk Mountain fossils show that by the Middle Miocene the *Eucalyptus* genus **s.l.** had differentiated into at least two of the phylogenetic groups as proposed by Johnson (1972, fig. 1). The fossil eucalypts show some features of advanced states in fruit and venation (L. A. S. Johnson, pers. comm.). This suggests that a suitable environment for their development must have existed very much earlier in the Tertiary. The paucity of eucalypt remains in the fossil record probably reflects the lack of opportunity for scleromorphic plants to become fossilized.

The lack of similarity between the Miocene pollen assemblages from the Gippsland Basin and Chalk Mountain is probably due to geographic and climatic factors rather than a great difference in age of deposition.

K/Ar dating of the basalts above and below the Chalk Mountain Formation is desirable to determine the exact age of the locality.

Acknowledgements

The authors wish to thank Mr V. Mills and Mr and Mrs G. Hawker of Bugaldie for assistance and information on the Chalk Mountain area; Dr J. W. Pickett and Dr

A. Ritchie for the loan of specimens from the Mining and Geological Museum and the Australian Museum respectively; Mr R. S. Jones for preparing the latex casts; Mr P. J. Althofer for making available his private collection; Professor N. C. W. Beadle, Mr J. B. Williams, Dr A. G. Floyd, Dr L. A. S. Johnson and Mr D. F. Blaxell for helpful discussion on the relationship of the fossils to extant species; Professor J. F. G. Wilkinson for information on the Warrumbungle Volcano; Mr D. Nelson and Dr J. A. Webb for useful comments and for information on their unpublished investigations of the Berwick fossil eucalypts. W. B. K. Holmes gratefully acknowledges support from the Science and Industry Endowment Fund.

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